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ECONOMIC REFORMS AND TECHNICAL EFFICIENCY: FIRM LEVEL EVIDENCE FROM SELECTED INDUSTRIES IN INDIA

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ABSTRACT

This paper analyses the performance of the manufacturing firms in some selected industries in terms of their technical efficiency against the background of the industrial and trade policy reforms introduced in India since 1991. A stochastic frontier production function and an associated inefficiency model are used to measure time varying firm specific technical efficiency. We define technical change as the shift of the best practice production frontier and technical inefficiency change as the movement within the best practice technology. The results show that all the industries considered registered a higher rate of technical progress in the post reform period along with a decline in the level of technical efficiency. The effect of change in the policy environment on technical efficiency varies among industries. The study also found that firms' involvement in the international trade through export and import of raw materials and technology has a positive effect on technical efficiency.

Key words: India, Manufacturing, Technical Efficiency, Economic Reforms.

JEL Classifications: D24, F13, L60, O30

I. Introduction

The industrial and external sector of the Indian economy witnessed major changes in their policy framework during the 1990s. These policy reforms are an integral part of the new economic policy initiated since 1991. The old industrial and trade policy regime, characterised by extensive public sector participation, regulation of the private sector firms, restrictions on foreign investment, high tariff and non-tariff restrictions on imports have been replaced by a more liberal industrial and trade policy regime. These policy changes are expected to have significant effect on the structure and performance of the Indian industry. An important objective of these policy reforms is to improve the production efficiency of Indian industry. In this paper, against the background of these policy reforms, we analyse the performance of the firms in some selected industries in terms of their technical efficiency. For this we use firm level panel data for ten years extending from pre to post reform period.

The paper is organised as follows. In the next section we provide a brief review of the reforms introduced in the industrial and external sector of the Indian economy and their relationship with firm's production efficiency[1]. In the third section we set out an empirical model to estimate time-varying firm-specific technical efficiency for

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1   For a detailed account of policy reforms in India see Srinivasan (2000)

Indian industry. A discussion of data and relevant variable construction is also provided in this section. Following this, in the fourth section we discuss the estimation strategy along with the results. A brief conclusion is provided in the fifth section.

II. Industrial and Trade Policy Reforms in India

The government of India announced its new industrial policy in June 1991. This industrial policy marked a major departure from the earlier import substituting and regulation oriented industrial policy framework. One of the major reforms in the industrial policy is the abolition of the complex system of industrial licensing, under which new investors setting up new units or existing ones undertaking major expansions had to obtain industrial license from the government. Industrial licensing system was abolished in all industries except in a small list of strategic and potentially hazardous industries and in a few industries, which are reserved for the small scale sector. Investment controls on large business houses, which was enforced under MRTP act, was also removed. So the firms belongs to the category of MRTP firms no longer needs prior approval from the government for investment in the delicensed industries.

The new policy also included many measures to improve the performance of state owned enterprises. The measures introduced in this direction include opening up of areas hitherto reserved exclusively for the public sector to the private sector and the decision to reduce the equity holdings of the government in public sector enterprises. Entry of private sector firms into dereserved industries creates more competition and is expected to improve the performance of the public sector firms. The policy of disinvesting public sector equity was expected to generate resources for the government's budget and at the same time subject these enterprises to the disciplining of stock market, leading to

improvement in their efficiency. The incentive to improve performance is also being increased by a conscious policy of phasing out budgetary support to fund losses in loss making enterprises. Foreign Exchange Regulation Act, 1973 (FERA) was substantially liberalised. All restrictions on FERA companies in the mattes of borrowing funds or raising deposits in India as well as taking over or creating any interest in Indian companies have been removed.

Other reform measures, which have a bearing on the industrial sector, include opening up of Indian securities market to registered foreign institutional investors (FII) for investments. Once registered with the securities and Exchange Board of India and RBI, the FII is allowed to undertake portfolio investment in the primary and secondary markets with certain limits on the extent of investment. Further, Indian companies were also permitted to tap foreign financial market by using instruments such as Global Depository Receipts and Euro Convertible bonds. A number of measures have been introduced to rationalise and reduce the excise, personal and corporate taxes and to extend the scope of vale added tax (VAT) and these changes in the tax structure are expected to reduce the tax burden and give more incentive to the industrial sector.

The reform measures in the external sector were introduced with the objective of opening up of Indian industry to foreign investment and technology and induce foreign competition via access to imports. The measures initiated in this direction included reduction in tariff and removal of non-tariff restrictions on imports, liberalisation of the foreign investment and technology import policies and exchange rate policy reforms.

Table 1. Mean Import Tariff of different Industrial groups

(in per cent)

	1990-91	1994-95	1997-98
Consumer goods	142 (33)	59 (33)	39.8 (20.5)
Intermediate goods	133 (42)	59 (17)	34.7 (10.3)
Capital goods	109 (32)	42 (20)	29.7 (9.4)

Note: Standard deviations are in parentheses.

Source: World Bank (1998).

Table 2.   Coverage Ratio for Non-Tariff Barriers on Indian Imports. (in per cent)

	1988-89	1995-96	1997-98
Consumer Non-durables	99.06	63.98	74.71
Consumer durables	84.34	52.75	40.18
Intermediate goods	83.47	44.78	39.21
Basic goods	57.51	25.17	19.28
Capital goods	74.12	22.77	16.63

Source: World Bank (1998)

As is evident from the above tables, with the reforms almost the entire manufacturing sector faced reduction in the rate of tariff and non-tariff protection. It should be noted that capital goods producing sector compared to other segments faced greater reduction in protection. Liberalisation of foreign direct investment (FDI) policy includes automatic approval up to 51 per cent in a large list of industries and setting up of Foreign Investment Promotion Board to expedite investment approvals in other industries and for investment above 51 per cent. With the liberalisation of the technology import, now automatic approval can be obtained for technology purchase or collaborations, provided the royalty or lump sum payment does not exceed the stipulated limit. The exchange rate system also underwent major reform process and was

transformed from a discretionary, basket pegged system to a largely market determined unified exchange rate system. A direct effect of these liberalisation measures can be seen in the increased trade intensity of the economy, increase in the foreign direct investment inflows and foreign technology collaborations in the 1990s.

These policy reforms can affect the production efficiency of firms in a variety of analytical ways [2]. First, the more freedom and flexibility now the firms have in choosing their optimum scale of operation, in their investment decisions, in the choice of technology, etc may induce them to produce at minimum cost of production. Secondly, increased domestic and foreign competition, a likely result of these policy changes, can also lead to more efficient industrial production. Increased competition affects the efficiency mainly through three ways, (a) inducing the firms to move towards the minimum point of the average cost curve (b) in a situation of free entry and exit, through the exit of the inefficient firms and absorption of their market share by more efficient firms. This would increase the industry level efficiency and (c) through an increase in the X-efficiency of the firms. The last point postulates that competition increases the managerial effort and this would increase the production efficiency (Corden, 1974; Rodrik, 1992)[3].

Besides the above arguments, it is also argued that opening up of the economy increases the domestic firms' access to better foreign technological knowledge and intermediate goods. This would also lead

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2   For a review of the theoretical literature and empirical evidence on the link between the trade policy reform and industrial productivity see Tybout (1992).

3   In the literature this argument is known as the X-efficiency argument of protection. Theoretical models developed by Corden (1974) and Martin (1978) tried to give an analytical basis for this argument. Formal modelling of X-efficiency argument in the context of trade liberalisation can be seen in Horn et al. (1995).

to higher production efficiency. The recent developments in the growth theory emphasis this knowledge transmission role of international trade (Grossman and Helpman, 1991a; 1991b and Romer, 1989). For instance to quote Coe et al. (1995) " an open trade policy regime increases the domestic producers' interaction with foreign producers and buyers. This interaction stimulates the cross border learning of production methods, product design, organisational methods and market conditions"(p: 136). In this literature, import and export of the commodities also assume the role as channels for the transmission of technological knowledge[4].

Some of the prominent studies that examined the effect of policy reforms, particularly, trade policy reforms, on technical efficiency include Tybout et al. (1991) Alam and Morrison (2000) and Tybout and Westbrook (1995). Tybout et al. (1991) analysed the effect of Chilean trade liberalisation on industrial efficiency. They found that reduction in tariff protection is correlated with increase in efficiency and decreases in variance of the efficiency scores. However, their results also show that eleven out of twenty one industries included in the study registered a decline in the level of efficiency after the trade reform. Further, the authors conclude that additional plant level studies, based on panel data and other trade liberalisation indicators are needed to confirm their findings. Another recent study by Alam and Morrison (2000) in the case of Peru shows that fifteen out of the twenty industries studied experienced an increase in the efficiency after the trade reform. Another study in the context of Mexico is by Tybout and Westbrook (1995). In this study the

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4   Romer (1989) emphasised both the productivity of specialised resources and the limitation given by the size of market in a restricted economy. The role of export from developing to developed countries in transferring technological knowledge is examined by various writers such as Eagan and Mody (1992) and Schmitz and Knorringa (2000). In this context to quote World Bank (1997) "Participating in export markets bring into contact international best practice and fosters learning and productivity growth" (p.74).

authors examine whether the changes in efficiency after the reform is correlated with changes in various measures of trade policy.

In Indian context a number of studies examined the effect of trade policy reform on total factor productivity in the nineties and these include studies by Balakrishnan et al. (2001), Krishna and Mitra (1998) and Kusum Das (1998). The study by Balakrishnan et al. (2001) used firm level panel data of industries that faced greater reduction in trade protection for the period 1988-89 to 1997-98. This study found that productivity growth is lower in the post reform period. Krishna and Mitra (1998) also used firm level panel data of some selected industries for the period 1986-1993. However, this study also could not find a strong evidence for the productivity effect of the reform. The study by Kusum Das (1998) analysed seventy six three digit industries covering the period 1980-81 to 1993-94. This study also found that productivity response to the trade policy reform is mixed. This study correlated the productivity growth with different measures of trade liberalisation. However, the results of this exercise show that in majority of the cases the trade liberalisation variable has a statistically insignificant positive relationship with productivity growth. There are also studies that examined the technical efficiency of the manufacturing industry in the 1990s. These include Agarwal (2001), Mitra (1999) and Agarwal and Goldar (1999). The first study analyses the performance of some selected public sector firms in terms of their technical efficiency and the second study focuses on the state wise analysis of technical efficiency of the manufacturing industry for the period 1976-77 to 1992-93. Agarwal and Goldar (1999) examined the determinants of the technical efficiency of firms.

The review of empirical studies shows that evidence on the proposition that policy reforms, particularly trade policy reforms, have

a positive effect on efficiency is rather inconclusive, despite a number of arguments supporting positive effect. After reviewing theoretical and empirical literature on the effect of trade policy on technical efficiency Deraniyagala and Fine (2001) observe that "the empirical evidence relating to trade policy and efficiency also fails to provide conclusive support for this argument" (p.811)[5].

Against this background we analyse the technical efficiency of some selected manufacturing industries in the context of these policy reforms and also test the effect of firm's involvement in international trade on technical efficiency.

III. Empirical Model and Data

III.1 Empirical Model

To measure the technical efficiency of firms over time and to test for the effect of firm's import and export activities on their technical efficiency, we are using a stochastic frontier production function, along with an inefficiency model as proposed by Battese and Coelli (1995)[6]. We assume that the frontier production function is of translog form as given in equation (1). This functional form is flexible and imposes fewer restrictions on the data.

$$ln Y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + \beta_m m_{it} + \beta_t t_{it} + \frac{1}{2}\beta_{kk}k_{it}k_{it} + \frac{1}{2}\beta_{ll}l_{it}l_{it} + \frac{1}{2}\beta_{mm}m_{it}m_{it} +$$

$$\frac{1}{2}\beta_{tt}t_{it}t_{it} + \beta_{kl}k_{it}l_{it} + \beta_{km}k_{it}m_{it} + \beta_{kt}k_{it}t_{it} + \beta_{lm}l_{it}m_{it} + \beta_{lt}l_{it}t_{it} + \beta_{mt}m_{it}t_{it} + v_{it} - u_{it} \quad (1)$$

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5 To quote Rodrik (1992) also "the evidence (on the technical efficiency effect of trade liberalisation) is too weak to sway any one with strongly held priors" (p.102).

6 Another very popular competing approach to efficiency measurement is the non parametric Data Envelopment Analysis (DEA). DEA imposes less structure on the frontier, but it does not allow for the random errors. It is not possible to determine which of the two approaches dominates the other since the true level of efficiency is unknown. In DEA all deviations from the frontier is interpreted as inefficiency and so stochastic frontier approach (SFA) normally yields lower inefficiency levels

The subscripts i and t indicate the observation for i^{th} firm in the tth year. Where lnY, k, l and m are the natural logarithm of output, capital stock, labour and material input respectively and t is the time trend included in the equation to allow the frontier to shift over time.

the v_{it} s are assumed to be independently and identically distributed normal random variables with mean zero and variance, σ_v^2 ; and

the u_{it} s are non-negative random variables, associated with technical inefficiency, which are assumed to be independently distributed, such that u_{it} is the truncation (at zero) of the normal distribution with mean, μ_{it}, and variance σ^2.

Where μ_{it} is defined as follows.

$$\mu_{it} = \delta_0 + \delta_1 TECH.INS_{it-1} + \delta_2 EX.INS_{it-1} + \delta_3 RAW.INS_{it} + \delta_4 R\&D.INS_{it-1} + \delta_5 t_{it} + \delta_6 t_{it}^2 + \delta_7 D_t + \delta_8 AGE_{it}$$
(2)

Where *TECH.INS, EX.INS, RAW.INS* and *R&D.INS* are firm's technology import intensity, export intensity, raw material import intensity and R&D intensity respectively. t and t^2 are the time trend and its square. Time trend and its square are included in the model to allow the inefficiency effects to change in quadratic fashion over time. This parametric model, as shown below, permits us to estimate the technical inefficiency change as a partial derivative of the inefficiency model with respect to the time variable. The variables AGE and D denote the age of the firm and a dummy variable respectively. A dummy variable is included in the model to capture the effect of the changed economic policy environment on technical *inefficiency*. The dummy takes value zero till 1991-92 and thereafter one.

Technical Efficiency (TE)

Technical efficiency score of the ith firm in t^{th} year (TE_{it}) is defined as follows

$$TE_{it} = exp(-u_{it})$$

This is the conditional expectation of u_{it} conditional upon the observed value of e_{it}, where e_{it} is equal to (v_{it} - u_{it}). Technical efficiency score is the ratio of the actual output of the firm to its frontier output, and so the technical efficiency equals one only if the firm has an inefficiency effect equal to zero, otherwise it is less than one.

Technical Change and Inefficiency Change

Following Battese and Broca (1997), the total effect of change in time on mean output can be expressed as follows[7] .

$$\frac{\partial \ln[\ E(Y_{it}\ )]}{\partial t} = (\beta_t + \beta_{tt} t + \beta_{kt} k + \beta_{lt} l + \beta_{mt} m) - C_{it}\left(\frac{\partial \mu_{it}}{\partial t}\right) \quad (3)$$

Where C_{it} is defined as follows

$$C_{it} = 1 - \frac{1}{\sigma}\left[\frac{\phi\left(\dfrac{\mu_{it}}{\sigma} - \sigma\right)}{\Phi\left(\dfrac{\mu_{it}}{\sigma} - \sigma\right)} - \frac{\phi\left(\dfrac{\mu_{it}}{\sigma}\right)}{\Phi\left(\dfrac{\mu_{it}}{\sigma}\right)}\right]$$

Where Φ and ϕ are the distribution and density functions of the standard normal random variable respectively.

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7   The details of the derivation are given in the appendix A2.

The first part of the expression (3), that is, $\beta_t + \beta_{tt} t + \beta_{kt} k + \beta_{lt} l + \beta_{mt} m$ is a measure of change in the frontier output with respect to time and it is called technical change (TC). A positive value for TC indicates that the frontier production function is shifting upward, implying technological progress in the industry and a negative value means the converse. The second part of the above expression, $-C_{it}\left(\dfrac{\partial \mu_{it}}{\partial t}\right)$, is called inefficiency change (IC) and it measure the rate at which technical efficiency changes with respect to time. A positive value for IC indicates that technical efficiency of the firm is increasing over time and a negative value indicates the opposite.

III.2 Data and Variable Construction

For our analysis we use firm level panel data of four industries, namely electrical machinery, electronics, non-electrical machinery and transport equipment. These industries belong to the segment of capital goods industries that faced greater reduction in trade protection in 1990s along with industrial policy reform. Hence, an analysis of these four industries assumes significance. The firm level data are obtained from the Centre for Monitoring Indian Economy's (CMIE) electronic database-PROWESS. The use of panel data allows us to have not only more number of observations, but also enables us to look into the pattern of distribution of technical efficiency among firms and its change over time. The panel is unbalanced and consists of 4735 observations on 640 firms. Since, we are using one year lagged values of some variables in our analysis, the data set used for estimating equation (1) and (2) consists of 4095 observations on 640 firms for the period 1989-90 to 1997-98. The construction of variables in the frontier production function (1) and the inefficiency model (2) are explained below.

Output: The database reports the value of the output of the firm. We have deflated value of the output thus obtained by the respective industry's wholesale price index. The wholesale price index is obtained from "Index Numbers of Wholesale Prices in India, base 1981-82 =100" published by the Economic Adviser Ministry of Commerce and Industry, Government of India[8] .

Capital: The capital input is the capital stock of the firm in 1981-82 prices. The database reports the Gross Fixed Assets (GFA) of the firm and its various components at historical cost. For constructing the capital stock of the firm, first we have converted reported GFA into replacement cost by taking 1994-95 as the base year on the basis of a revaluation factor. For computing the revaluation factor we have followed Srivastava's (1996) procedure. Capital stock series is then constructed by using perpetual inventory method[9].

Labour: The variable labour input is measured in terms of labour hours. The database reports the total wages paid to the employees, including the managers. We have used the wage rate per hour obtained from the corresponding industrial classification of Annual Survey of Industries (ASI) to construct labour hours from the total wages.

Raw materials: The raw material input is constructed by deflating the raw material cost by raw materials price index. Raw materials price index is constructed by using weights obtained from the Input-Output Transaction Table of India for 1989-90 published by the Central Statistical Organisation (CSO) and appropriate price indices collected

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8   The wholesale price index is available only at the industry level. Therefore, this approach is unable to account for the firm level price differences due to the productivity differences at the firm level. So output deflation at the industry level may result in the smoothing of some of the productivity differences at the firm level.

9   The details on the construction of the capital stock are given in the appendix.

from Index Numbers of Wholesale Prices in India, base 1981-82 =100. Raw materials cost includes all expenditure on intermediate inputs and energy consumed in the process of production.

The construction of variables in the inefficiency model (2) is explained below.

1. *Technology Import Intensity (TECH.INS)*: Technology import of the firms is represented by its technology import intensity. It is the ratio of firm's expenditure on technology import to its sales value in a year. The technology import expenditure includes the expenditure on the import of capital goods embodying new technology as well as the import of disembodied technology through licensing. One-year lag is assumed in the effect of technology import on technical *inefficiency*.

2. *Export Intensity (EX.INS)*: Firm's extent of interaction with the foreign buyers and foreign markets and the consequent learning from them is represented by its export intensity. It is defined as the ratio of firm's export to its sales value in a year. It is assumed that firm's previous year export experience has a positive effect on current year technical efficiency. Hence, export intensity is included in the equation with a year lag.

3. *Raw material Import Intensity (RW.INS):* The degree of utilisation of imported *raw materials* by the firms is measured by its raw material import intensity. This is defined as the ratio of the value of raw materials imported to total raw materials used in production in a year.

4. *R&D Intensity (R&D.INS)*: Firm's effort to develop, adapt and absorb new technology is measured by its R&D intensity. This is defined as the ratio of firm's R&D expenditure to its sales value. One-year lag is assumed in the effect of R&D investment on technical *inefficiency*.

5. *Age (AGE)*: Age of the firm is included in the inefficiency model to control for the effect of experience of the firm on technical inefficiency. The age of firm is calculated from the year of incorporation of the firm. Logarithm of firm age is used because an additional year of experience of a firm is expected to have greater influence on new firms than on older ones.

IV. Estimation and Results

The frontier production function defined by (1) and the inefficiency model defined by (2) are estimated simultaneously by using maximum likelihood method[10] for each industry separately. This simultaneous estimation is considered to be superior to the two-stage estimation because of two reasons. First, the two-stage estimation is inconsistent in its assumption regarding the independence of the inefficiency effects in the two estimation stages (Coelli, 1996a). Second, the efficiency scores are bounded variables, either by zero and one or below one, so it is not suitable to use OLS to estimate the function, because of the non normality and bounded range of the error term (Lovell, 1993). The parameter estimates of the frontier production function and inefficiency model are given in table A1 in the appendix. The variance parameters are estimated in terms of $\gamma = \sigma^2/(\sigma^2 + \sigma_v^2)$ and $\sigma_s^2 = (\sigma^2 + \sigma_n^2)$.

We test for various restrictions on the translog production frontier and inefficiency model, which consists of large number of parameters, to decide whether a simpler model would be an adequate representation of the data. For this we use the generalised likelihood-ratio (LR) statistic as defined below.

$$\lambda = -2\left[\ell(H_0) - \ell(H_1)\right]$$

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10   For estimating the model (1) and (2) I have used Frontier 4.1 computer programme, which uses DFP iterative method to obtain the maximum likelihood estimates. More details about the programme can be seen in Coelli (1996b). For the log likelihood function and the methodology for estimating the time varying firm specific technical efficiency scores, which is used by the Frontier 4.1 see Battese and Coelli (1993).

Where $l\,(H_0)$ is the log likelihood value of the restricted frontier model as specified by the null hypothesis H_0 and $l\,(H_1)$ is the log likelihood value of the unrestricted frontier model under alternative hypothesis H_1. This test statistic has a chi-square (or a mixed chi-square distribution) with degrees of freedom equal to the difference between the parameters in the null and alternative hypothesis. Table 3 presents the results of these tests.

Table 3.   Test for restrictions on Frontier Production Function and Inefficiency Model

H0	Electrical Machinery	Electronics	Non-electrical Machinery	Transport Equipment	Critical Value*
	(χ^2)	(χ^2)	(χ^2)	(χ^2)	(χ^2)
1. Cobb-Douglas Production Function	80.86	654.54	201.92	193.96	16.92
2. No Technical Change $(\beta_t = \beta_{tt} = \beta_{kt} = \beta_{lt} = \beta_{\mu\tau} = 0)$	51.60	150.08	49.28	162.22	11.07
3. No Technical inefficiency $(\gamma = \delta_0 = \ldots = \delta_8 = 0)$	157.4	181.98	131.16	619.66	16.27#
4. $\delta_1 = \delta_2 = \ldots = \delta_8 = 0$	37.82	53.42	41.2	73.52	15.51
5. No Time Effect $(\delta_2 = \delta_3 = 0)$	32.68	44.18	21.54	6.84	5.99

*   All critical values are at 5 percent level of significance,

\#   This critical value is obtained from table 1 of the Kodde and Palm (1986). The null hypothesis which includes the restriction that γ is zero does not have a chi-square distribution, because the restriction defines a point on the boundary of the parameter space. In this case the LR statistic follows a mixed chi-square distribution with degrees of freedom equal to 9, if H_0 is true.

The first two null hypotheses are concerned with production frontier and the rest with the inefficiency model. The first null hypothesis that frontier production function is of Cobb-Douglas form is rejected by the data in all industries, given the translog functional form. This indicates that input elasticity and substitution relationships are not constant for firms of different sizes and with different input values in the four industries. The second null hypothesis of no technological progress at the frontier is also rejected, implying shift of the production frontier over time.

The null hypothesis of no technical inefficiency effects is rejected in all industries, given the translog production function. This shows that production function is not equivalent to the traditional average response function, which can be efficiently estimated using ordinary least squares regression. The fourth restriction that coefficients of all the explanatory variables in the inefficiency model are simultaneously equal to zero, implying that they are not useful in explaining technical inefficiency is also rejected. Lastly, the hypothesis that the coefficients of time and its square are equal to zero is also rejected. Thus the hypotheses testing results show that our specification of equations (1) and (2) are more suitable to the data compared to other alternative specifications.

IV.1 Technical Efficiency and its Determinants

Technical efficiencies for the sample firms in the four industries are predicted for each year. Here we are reporting only the summary measures of these estimates. The average level of technical efficiency for the entire period is high in all industries and it varies from 0.916 in electrical machinery to 0.850 in transport equipment. We estimate two measures of average efficiency for each year, first is a simple average across firms and second is a weighted average efficiency, by taking the

firm's share in the total output of the sample firms in that year as the weight. The weighted average efficiency can be considered as a better measure of average efficiency for the industry, since firms having a higher level of output would get a higher weight in the mean efficiency calculation. Tables 4 & 5 present these estimates. The trend of the unweighted mean technical efficiency scores show that it is lower in the post reform period (1992-3 to 1997-8) in all industries compared to the pre reform period. The weighted mean technical efficiency scores also show a similar trend in all industries (table 5). A comparison of the weighted mean efficiency with unweighted mean efficiency shows that the former measure is always higher than the latter, indicating that large firms, in terms of output, have higher technical efficiency. This may also be due to the fact that more efficient firms are producing larger share of the output. Further, a comparison of the extent of decline in technical efficiency shows that the decline is more pronounced in the case of unweighted mean efficiency than the weighted mean efficiency, implying that the decline in the technical efficiency level is mainly concentrated among firms producing lower level of output.

Theoretically, the policy reforms, especially trade policy reforms, are expected to bring about convergence in the efficiency levels of the firms in an industry. The estimated standard deviation of the unweighted efficiency scores, however, shows an increasing trend over the years in all industries. This shows more divergence rather than convergence in efficiency levels.

The estimates of inefficiency model (given in table A1 in appendix) gives how the technical *inefficiency* is related to variables of our interest[11]. The dummy variable representing the change in the economic policy environment since 1991 has a significant negative

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11   Note that the depended variable in the inefficiency model is *technical inefficiency*.

Table 4. Unweighted Mean Technical Efficiency (MTE) scores.

Year	Electrical Machinery		Electronics		Non-electrical Machinery		Transport Equipment	
	M.T.E	S.D	M.T.E	S.D	M.T.E	S.D	M.T.E	S.D
1989-90	0.970	0.0064	0.925	0.0216	0.934	0.0288	0.887	0.1141
1990-91	0.961	0.0113	0.893	0.0521	0.931	0.0260	0.872	0.1183
1991-92	0.934	0.0320	0.876	0.0627	0.914	0.0369	0.849	0.1197
1992-93	0.948	0.0199	0.879	0.0846	0.888	0.0662	0.838	0.1228
1993-94	0.939	0.0264	0.871	0.0796	0.906	0.0671	0.852	0.1568
1994-95	0.906	0.0618	0.835	0.1045	0.903	0.0736	0.841	0.1617
1995-96	0.884	0.0768	0.811	0.1360	0.890	0.0888	0.866	0.1404
1996-97	0.858	0.0743	0.777	0.1571	0.869	0.0884	0.825	0.1576
1997-98	0.845	0.0993	0.790	0.1290	0.843	0.1053	0.810	0.1446

Note: S.D = Standard Deviation of Technical Efficiency Scores.

Table 5. Weighted Mean Technical Efficiency Scores.

Year	Electrical Machinery	Electronics	Non-electrical Machinery	Transport Equipment
1989-90	0.974	0.928	0.937	0.914
1990-91	0.965	0.910	0.934	0.902
1991-92	0.942	0.889	0.919	0.875
1992-93	0.953	0.898	0.906	0.853
1993-94	0.945	0.890	0.921	0.889
1994-95	0.918	0.855	0.915	0.905
1995-96	0.899	0.842	0.915	0.958
1996-97	0.879	0.841	0.900	0.904
1997-98	0.880	0.842	0.882	0.882

sign in electrical machinery and electronics. This indicates that the change in the policy has a favourable effect on technical efficiency. In non-electrical machinery the policy dummy has a significant positive sign, indicating that post 1991 period has an unfavourable effect on its efficiency. Export intensity and raw material import intensity has significant negative effect on technical inefficiency in non-electrical and transport equipment industries, suggesting that previous years export experience and access to better or cheaper raw materials are contributing positively to efficiency. In electronics the raw material import intensity has significant positive sign; one possible reason for this result can be the depreciation of the exchange rate of the rupee and the consequent increase in the cost of raw material import[12]. In this industry this cost hike may have been higher than their efficiency enhancing effect. Technology import intensity and R&D intensity have negative sign in all industries and supports our hypothesis that access to technology import is contributing to efficiency enhancement. Agarwal and Goldar (1999) examined the effect of export intensity and technology import intensity along with other variables on technical efficiency of the engineering firms in India. They estimated the relationship for the pre and post reform period separately. Their results for the post reform period, based on averaged firm level data for the period 1992-3 to 1994-5, also show that technology import and export are positively related to technical efficiency. The age variable is negatively related to technical inefficiency in all industries except electrical machinery, showing that age, a proxy for the experience of the firms is contributing positively to efficiency. In electrical machinery the positive sign of the age variable may be due to the fact that age is reflecting the age of the capital stock rather than the experience of the firms.

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12   Electronics industry has the highest raw material import intensity compared to other three industries.

IV. 2 Technical Change and Inefficiency Change

We estimate technical change (TC) and inefficiency change (IC) for each observation and are reporting average of these estimates for each year, for the entire period of study, as well as for the pre and post reform periods. Tables 6 & 7 present these estimates.

Table 6. Technical Change (TC) and Inefficiency Change (IC)

	Electrical Machinery		Electronics Machinery		Non-electrical Equipment		Transport	
	TC	IC	TC	IC	TC	IC	TC	IC
Entire Period	0.018	-0.023	0.059	-0.025	0.019	-0.012	0.030	-0.010
(1989-0 to 1997-8)	(2.66)	(-3.69)	(5.77)	(-6.72)	(3.02)	(-4.63)	(5.18)	(-6.11)
Pre reform period	-0.003	-0.021	0.049	-0.033	0.001	-0.012	0.017	0.001
(1989-0 to 1991-2)	(-0.38)*	(-3.54)	(4.23)	(-22.85)	(0.02)*	(-4.57)	(2.75)	(0.82)*
Post reform period	0.024	-0.023	0.062	-0.023	0.024	-0.016	0.034	-0.014
(1992-3 to 1997-8)	(3.51)	(-3.73)	(6.19)	(-5.43)	(4.10)	(-6.20)	(6.06)	(-7.77)
Difference	0.027	-0.001	0.013	0.010	0.023	-0.004	0.017	-0.015
	(34.74)	(-0.82)*	(29.08)	(5.26)	(41.72)	(-6.34)	(40.70)	(-34.14)

Note: t values are in parentheses and * indicates not significant at 1 % level of significance.

Table 7. Technical Change and Inefficiency Change.

Year	Electrical Machinery		Electronics		Non Electrical Machinery		Transport Equipment	
	TC	IC	TC	IC	TC	IC	TC	IC
1989-90	-0.009	-0.007	0.046	-0.025	-0.005	0.002	0.013	0.004
1990-91	-0.003	-0.020	0.048	-0.029	0.001	0.001	0.017	0.001
1991-92	0.002	-0.033	0.051	-0.040	0.006	0.000	0.021	-0.001
1992-93	0.008	-0.017	0.054	-0.024	0.010	-0.003	0.024	-0.004
1993-94	0.014	-0.024	0.057	-0.030	0.015	-0.005	0.027	-0.006
1994-95	0.020	-0.030	0.060	-0.033	0.021	-0.009	0.032	-0.010
1995-96	0.025	-0.032	0.062	-0.030	0.027	-0.014	0.036	-0.014
1996-97	0.033	-0.024	0.066	-0.018	0.032	-0.023	0.040	-0.019
1997-98	0.040	-0.005	0.069	-0.002	0.036	-0.036	0.043	-0.026

The last row of the table 6 shows the change in TC and IC in the post reform period over the pre reform period[13] . The estimates of technical change for the entire period varied from 1.82 per cent per annum in electrical machinery to 5.95 per cent in electronics. In all industries the difference between the pre and post reform period is positive and statistically significant, showing a significant improvement in the rate of technical change in the post reform period, with electrical machinery recording the highest improvement. In the post reform period also electronics has the highest rate of technical change, 6.2 per cent per annum.

Regarding the rate of inefficiency change the estimates shows that for the entire period of study inefficiency change is negative in all industries, showing that efficiency is declining over the years. For the entire period the rate of decline in technical efficiency is highest in electronics, -0.025 and this rate of decline is lowest in transport equipment industry, -0.010. The difference between the pre and post reform rate of inefficiency change is negative and statistically significant in non-electrical and transport equipment industries; implying an increase in the rate of decline in the technical efficiency in the post reform period. In electronics the rate of decline in the technical efficiency is significantly lower in the post reform period and in electrical machinery there is no significant change in the rate between the two periods. Further, in these two industries from 1995-96 onwards the rate of decline in technical efficiency is weakening. This indicates that in these two industries firms are showing signs of catching up with the frontier technology. The other two industries, on the other hand show an

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13   We have used t test for the difference of means to test for the difference in averages between the two periods.

acceleration in the rate of decline in technical efficiency during the end of the study period (see table 7) [14].

The results show that in all industries technical efficiency is declining in a context of technical progress, identified as the upward shift of the industry's best practice technology. This indicates that majority of the sample firms in these industries failed to catch up with the shifting production frontier. Technical change is the result of innovation or adoption of new technology by the best practice firms. In a context of positive technical change in the industry, adoption and mastering of the new technology by the interior firms are necessary to maintain higher level of efficiency. This needs explicit resource allocation as well as capability on the part of these firms along with conducive institutional and infrastructure facilities (Nishimizu and Page, 1982). Within the framework of the present study, therefore, we do not venture to explain the reasons for the lower technical efficiency along with higher technical progress. For achieving higher total factor productivity growth continuously for a long period of time, it is necessary to have higher technical progress accompanied with high level of technical efficiency of the firms[15]. So further studies looking into the

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14   By taking the first derivative of the inefficiency model with respect to time equal to zero and solving it for time, we can find out the year in which the level of technical *inefficiency* is reaching its maximum or minimum and thereby the patterns of inefficiency change. This exercise shows that in electrical machinery and electronics, technical *inefficiency* is increasing in the initial years and reaches its *maximum* in the 9th year and thereafter decreasing. In non-electrical and transport equipment industry, on the other hand, the level of technical inefficiency is declining in the initial years and reaches its *minimum* in the third year in non-electrical machinery and 2.5th year in transport equipment industries and thereafter the level of technical *inefficiency* is increasing in both the industries.

15   In this context to quote Nishimizu and Page (1982), "High rates of technological progress can co-exist with deteriorating technical efficiency-perhaps due to failure in achieving technological mastery or due to short run cost minimising behaviour in the face of quasi fixed vintage capital-thus with low or the often observed negative rates of total factor productivity change" (p: 924).

reason behind the failure of the firms to catch up with the technological progress happening in their respective industries deserve greater importance.

Further, a reading of the results of this study against the results of a total factor productivity study for the same time period by Balakrishnan et al. (2001) would be interesting. Using firm level panel data of industries that faced greater reduction in trade protection, the above study found that productivity growth is lower in the post reform period. The results of the present study show that it is the technical efficiency and not the rate of technical progress that is lower in the post reform period.

V. Conclusion

We analyse the performance of the firms in four selected industries in terms of efficiency against the background of economic policy reforms introduced in India since 1991. The results indicate that although, the change in the policy environment has a positive effect on the technical efficiency in all except in one industry, the level of efficiency is lower in the post reform period in all the industries considered. The decline in the level of technical efficiency happened in a context of higher technical progress, identified as the upward shift of the best practice technology in all industries. This indicates that majority of the firms failed to catch up with the shifting frontier technology, resulting in an increase in their inefficiency. The hypothesis that a more liberalised trade regime enables the firms to acquire foreign technological knowledge through their export, import of technology and raw material import and thereby enhance the production efficiency was also examined. In this respect we found that firm's export activity, import of technology and raw materials are contributing to higher efficiency.

Appendix

Table A1. Coefficients Estimates of the Production Function and Inefficiency Model

	Electrical Machinery	Electronics	Non-electrical Machinery	Transport Equipment
Production function				
Constant	0.701 (1.07)	3.150 (3.17)	-1.850 (-3.04)	1.421 (2.39)
β_k	0.081 (0.922)	0.418 (2.72)	0.443 (5.53)	0.267 (2.12)
β_l	0.375 (5.39)	0.884 (7.19)	-0.165 (-1.71)	-0.030 (-0.34)
β_m	0.662 (6.27)	-0.295 (-2.59)	1.022 (12.36)	0.724 (9.21)
β_t	-0.045 (-1.47)	0.007 (0.14)	-0.047 (-1.46)	0.007 (0.25)
$0.5\beta_{kk}$	0.027 (2.55)	0.007 (0.39)	0.118 (10.22)	0.131 (8.16)
$0.5\beta_{ll}$	0.042 (3.78)	0.093 (5.67)	-0.026 (-1.77)	0.042 (3.50)
$0.5\beta_{mm}$	0.080 (5.20)	0.231 (24.94)	0.076 (6.62)	0.106 (9.91)
$0.5\beta_{tt}$	0.007 (3.18)	0.003 (0.99)	0.005 (2.77)	0.004 (2.35)
β_{kl}	0.009 (1.18)	0.040 (2.99)	-0.011 (-1.01)	-0.031 (-2.48)
β_{km}	-0.031 (-3.37)	-0.057 (-5.57)	-0.130 (-12.95)	-0.112 (-10.71)
β_{kt}	-0.007 (-2.73)	0.001 (0.12)	-0.001 (-0.24)	-0.005 (-1.34)
β_{lm}	-0.056 (-5.51)	-0.153 (-9.34)	0.049 (5.21)	0.007 (0.78)
β_{lt}	0.006 (2.42)	0.003 (0.72)	-0.005 (-1.48)	-0.001 (-0.12)
β_{mt}	0.004 (1.24)	-0.001 (-0.28)	0.007 (2.24)	0.005 (1.87)
Inefficiency model				
Constant	-1.977 (-5.19)	-5.29 (-9.05)	-1.39 (-3.02)	-0.674 (-1.93)
TECH.INS	-0.003 (-0.05)	-7.291 (-3.71)	-5.011 (-3.87)	-4.160 (-19.41)
EX.INS	-0.154 (-1.39)	-0.084 (-0.61)	-0.885 (-6.19)	-3.374 (-20.64)
RAW.INS	0.044 (0.46)	0.601 (4.22)	-1.841 (-24.33)	-0.911 (-15.40)
R&D.INS	-12.712 (-3.98)	-9.90 (-9.27)	-3.247 (-0.82)	-47.422 (-32.74)
t	0.504 (4.42)	1.275 (22.65)	-0.169 (-1.58)	-0.283 (-3.15)
t^2	-0.027 (-3.69)	-0.070 (-13.06)	0.029 (4.01)	0.055 (5.88)
D	-0.524 (-3.83)	-1.284 (-10.69)	0.622 (3.09)	-0.083 (-0.57)
AGE	0.089 (4.53)	-0.065 (-1.46)	-0.230 (-6.33)	-1.940 (-37.15)
$\sigma_s = (\sigma^2 + \sigma_v^2)$	0.049 (9.72)	0.435 (5.07)	0.255 (7.34)	1.435 (20.41)
$\gamma = (\sigma^2/\sigma^2 + \sigma_v^2)$	0.806 (36.15)	0.930 (53.21)	0.931 (66.39)	0.995 (1636.72)
LLF [#]	615.2	-13.53	397.35	272.43
Observations	998	862	1157	1078

Note: t values of the parameters are in brackets,

   # Log likelihood value

A1. Measurement of Capital.

In the frontier production function estimation, the capital variable is the capital stock of the firm in 1981-82 price. In this study to construct the capital stock of the firms we have used Srivastava's (1996) procedure. This method is explained in detail below.

The database gives information on gross fixed asset (GFA), it's various components and depreciation. Capital stock of some firms is revalued and this revaluation portion is reported separately in the database. First, we subtracted the value of capital under construction and revaluation portion, if any, from the reported GFA. Taking the difference between the current and lagged values of GFA thus obtained gives the actual investment that enters into the production process. This enables us to use perpetual inventory method to construct capital stock, as given below

$$k_{t+1} = k_t + I_{t+1}$$

$$k_t = k_{t-1} + I_t$$

$$k_{t-2} = k_t - I_t - I_{t-1}$$

and so on

Where k_{t+s} and I_{t+s} are the capital stock and the real investment respectively at time t+s. The application of this method requires a base year capital stock k_t that is valued at replacement cost. The reported GFA is measured in historical cost, therefore, we have to choose one base year and revalue that year's capital stock. In this study we took 1994-95 as the base year for the estimation of capital stock. The rationale for taking 1994-95 as the base year is the availability of largest number of observations for this year.

Capital Stock at Replacement Cost in the base year

Since we don't have a capital stock at replacement cost in the base year, the base year capital stock needs to be revalued so as to obtain its value at replacement cost. Given the available data, there is no perfect way of doing this and any method used is an approximation. The method that we have used is based on the following assumptions.

1. No firm has any capital stock in the base year (1994-95) of a vintage earlier than 1975-76. The year 1975-76 itself is chosen because the life of a machinery is assumed to be twenty years, as noted in the report of the Census of Machine Tools (1986) of the Central Machine Tool Institute Bangalore ('National Accounts Statistics: Sources and Methods' New Delhi: Central Statistical Organisation, 1989). For firms incorporated before 1975-76 it is assumed that the earliest vintage capital in their capital mix dates back to the year of incorporation. Clearly, as stated by Srivastava (1996) the year of incorporation and the vintage of the oldest capital in the firm's asset mix may not coincide for some firms, but the assumption is made for want of a better alternative.

2. The price of capital has changed at a constant rate, π

$$\pi = \frac{P_t}{P_{t-1}} - 1$$

from 1975-76 or from the date of incorporation of the firm (which ever is later) up to 1994-95 (base year). Values for π were obtained by constructing capital formation price indices from the series for gross fixed capital formation in manufacturing obtained from various issues of the National Account Statistics of India. The constant inflation rate π is not firm specific but it varies with the year of incorporation, provided the firm was incorporated after 1975-76.

3. Investment has increased at a constant rate for all firms and the rate of growth of investment (g) is

$$g = \frac{I_t}{I_{t-1}} - 1$$

Here the rate of growth of gross fixed capital formation in manufacturing at 1980-81 prices is assumed to apply to all firms. Again different average annual growth rates are obtained for firms established after 1975-76.

Making these assumptions the revaluation factor R^G for the base year gross fixed capital stock can be obtained as described below. The balance sheet value of assets in the base year is scaled up by the revaluation factor to obtain an estimate of the value of capital stock at replacement costs.

Replacement Cost of Capital = R^G x [Value of Capital Stock at Historic Cost]

The revaluation factors can be obtained as follows

Revaluation Factor for Gross Fixed Assets (R^G)

Let us denote GFA_t^h and GFA_t^r are gross fixed asset at historical costs and replacement costs respectively and I_t is the real investment at time t . By definition and making the assumptions mentioned above.

$$GFA_t^h = P_t I_t + P_{t-1} I_{t-1} + P_{t-2} I_{t-2} + ...$$

And
$$= P_t I_t \left(\frac{(1+g)(1+\pi)}{(1+g)(1+\pi)-1} \right)$$

$$GFA_t^r = P_t I_t + P_t I_{t-1} + P_t I_{t-2} + ...$$

$$= P_t I_t \left(\frac{(1+g)}{g} \right)$$

Defining R^G

$$R^G = \frac{GFA_t^r}{GFA_t^h}$$

Then

$$R^G = \frac{(1+g)(1+\pi)-1}{g(1+\pi)}$$

If it is assumed more realistically that the capital stock does not dates back infinitely, but that the capital stock of the earliest vintage is t period old, then we can derive the revaluation factor as follows.

$$R^G = \frac{[(1+g)^{t+1}-1](1+\pi)^t[(1+g)(1+\pi)-1]}{g\{[(1+g)(1+\pi)]^{t+1}-1\}}$$

We have used GFA thus obtained, after deflating it with the whole sale price index for machinery and machine tools with base 1981-82 =100, in the estimation of frontier production function.

Finally, in this study we have used gross fixed asset of the firm rather than net fixed asset. For estimating the net fixed asset of the firm we need information on accounting and economic rate of depreciation. Reliable data on accounting and economic rate of depreciation are not available in India. Further, Dennison (1967) argues that the correct measure of capital stock falls some where between gross and net stock of capital, advocating the use of a weighted average of the two with higher weight for the gross asset as the true value is expected to be closer to it.

A2. Calculation of Elasticities of Mean Output

The stochastic frontier function is expressed by

$\ln Y = x\beta + V - U,$

where the subscripts are omitted for simplicity;

V has N(0, σ_V^2) independent of U which has truncated normal distribution, N(μ, σ^2).

Given the assumptions about the distributions of V and U, it can be shown that

$$\ln\{E(Y)\} = x\beta + 0.5\,\sigma_v^2 + \ln\{E(e^{-U})\}$$

and
$$E(e^{-U}) = e^{-\mu + 1/2\sigma^2}\left\{\Phi\left(\frac{\mu}{\sigma} - \sigma\right)\Big/\Phi\left(\frac{\mu}{\sigma}\right)\right\}$$

The elasticity of mean output with respect to x_1 can be shown to be

$$\frac{\partial \ln E(Y)}{\partial x_1} = \frac{\partial x\beta}{\partial x_1} - C\frac{\partial \mu}{\partial x_1}$$

where
$$C = \left\{1 - \frac{1}{\sigma}\left[\frac{\phi\left(\frac{\mu}{\sigma} - \sigma\right)}{\Phi\left(\frac{\mu}{\sigma} - \sigma\right)} - \frac{\phi\left(\frac{\mu}{\sigma}\right)}{\Phi\left(\frac{\mu}{\sigma}\right)}\right]\right\}$$

and $\phi(.)$ and $\Phi(.)$ denote the standard normal density and distribution functions, respectively.

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